1997 Los Angeles Basin Passive Seismic Experiment:

By Monica Kohler

Shallow subsurface structures can sometimes focus seismic waves produced by earthquakes, resulting in enhanced earthquake damage. For example, the large amount of damage that occurred in Santa Monica after the Northridge earthquake may have been caused by focusing of seismic energy.

To prepare for such potential hazards, estimates of how hard the ground will shake at specific sites during earthquakes can be made from seismic data. Although significant progress has been made in understanding how faulting occurs in southern California, the San Gabriel Valley-northern Orange County region is one where there is still a paucity of good seismic data. The data are necessary to elucidate crustal and upper mantle structure needed in ground motion prediction, model validation, and tectonic evolution studies. The 1997 Los Angeles Basin Passive Seismic Experiment was designed to fill the gap.

The high-density LABPSE array, composed of SCEC short-period seismometers, was installed across the entire L.A. basin from March to November 1997. The array was designed and maintained by UCLA seismologists to investigate shallow Earth structure beneath the San Gabriel and L.A. basins.

We recorded local, regional, and teleseismic earthquakes continuously during the experiment (see sidebar "The Stats"). Most of the 18 stations, including those in the deep portions of the basins, recorded both local and teleseismic events with unprecedented clarity and waveform coherence. The goals of the experiment were to:

Quantify amplification of ground motion from variations in sedimentary environments and subsurface structures

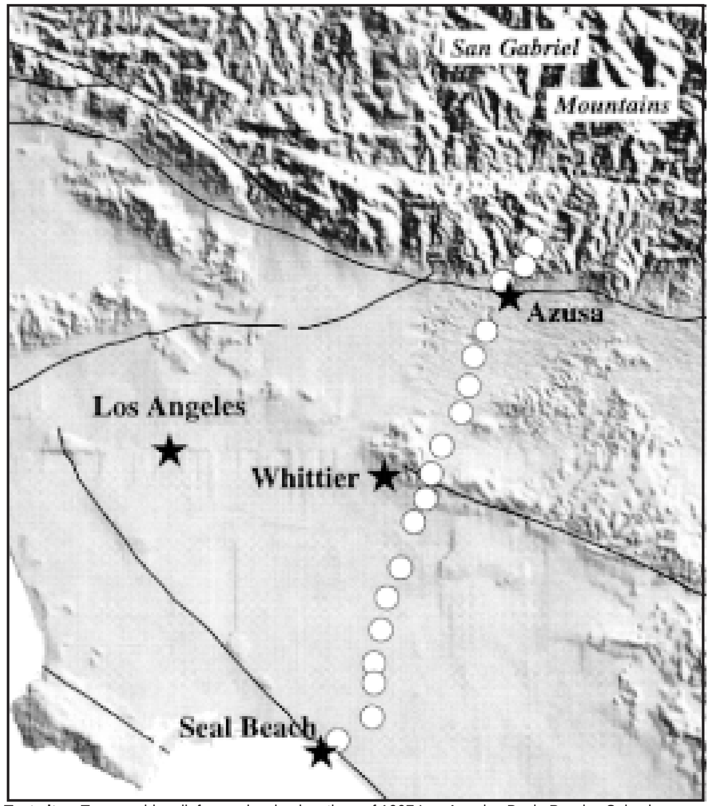
Examine the tectonic extensional and compressional history of the L.A. basin and San Gabriel Mountains by tomographic imaging.

The Array

The LABPSE array spans the L.A. basin between Seal Beach and Azusa with an average station spacing of 3-4 km. This is a much denser seismic array than any other in the region.

The LABPSE Stats

- 18 short-period, 3-component SCEC seismometers (L4C3D 1-Hz sensors, Reftek Data Acquisition Systems with 16-bit and 24-bit digitizers, GPS receivers)
- Data collection by field disk swaps
- 3-km average station spacing throughout L.A. basin
- 50-km total array length from Azusa to Seal Beach. Most locations were backyards with continuous AC power sources and battery backup
- 9 months of teleseismic, regional, and local event recording (March-November 1997)
- Continuous recording at 25 sps, triggered at 50 sps



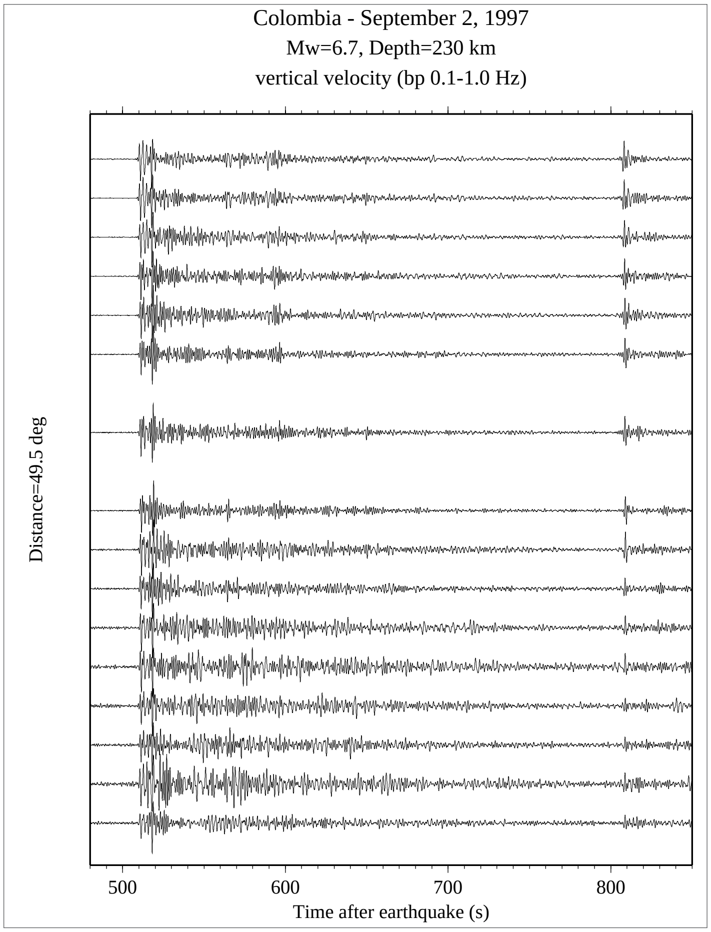
Test sites. Topographic relief map showing locations of 1997 Los Angeles Basin Passive Seismic Experiment stations (circles) and nearby cities (stars).

The close spacing of seismometers is providing highly detailed information about the geometry of structures several kilometers below the surface. The high density of stations makes it possible to observe amplitude variations on length scales of a few kilometers and to obtain travel times in seismically and culturally noisy regions by cross-correlation with quiet stations using the highly coherent waveforms.

We chose this array location because it spans the entire L.A. basin, and it covers an area known for its unique geology and plate tectonics. It was also the site of one leg of the 1994 Los Angeles Region Seismic Experiment (LARSE), in which onshore and offshore explosions were recorded along essentially the same line for very detailed structure in the upper 20 km of the Earth's crust. We also needed the relatively long nine months of experiment time so that a large number of teleseisms from large earthquakes would be seen at the noisier basin stations.

The southern foothills of the San Gabriel Mountains are a Miocene depositional basin with widely varying sedimentary thickness and lithology (Yerkes and others, 1965). The high-angle, reverse San Gabriel frontal fault segment of the Sierra Madre-Cucamonga fault system defines the southern base of the San Gabriel Mountains. It dips northward into the San Gabriel Mountain's granitic and metamorphic rocks and is adjacent to unconsolidated alluvial fan deposits lying to the south, characterizing the northern San Gabriel Valley

Subsurface Imaging in a Densely Populated Urban Setting



Teleseismic data. A profile of seismograms recording an event that occurred in Colombia on September 2, 1997 (M 6.7). They are arranged in order with the northernmost stations on top.

(Yerkes and others, 1965). The L.A. basin and San Gabriel Mountains are characterized by markedly different geological blocks and the changing geology is reflected in profiled seismograms across the array.

The northernmost San Gabriel Mountain foothill stations in Azusa are on bedrock or thin alluvial fan sediments and display the highest signal-to-noise ratios. They are followed to the south by several stations sitting on ~3 km of sediments that make up the San Gabriel Valley, a small sedimentary basin within the larger L.A. basin. The increase in sedimentary thickness (i.e., the increased depth of basement) results in scattered waveforms, showing more phase complexity than the bedrock stations.

The central three stations in the Puente Hills are separated from the bulk of deeper-sediment (up to ~7 km) basin stations farther south by the Whittier fault. The southernmost stations are near the coast in Seal Beach and cross the Newport-Inglewood fault. Waveform coherence is spectacular across the array, regardless of environment. The figure “Teleseismic data” shows teleseismic arrivals from an event that occurred in Colombia, for example.

The Geology

The mid-Tertiary East Pacific Rise collision with the North America plate and subsequent crustal extension are supported by geological evidence for mid-Miocene rifting and volcanism (Wright, 1991) associated with the opening of a rift basin by extension accompanied by high heat flow (Henyey, 1976). Crustal extension coincides with episodes of pervasive, clockwise block rotation throughout southeast California and is related to changing Farallon subduction deformation style (Luyendyk, 1991).

The L.A. basin contains numerous high-angle faults that make up a shattered, brittle crust often associated with crustal thinning and block faulting over a mobile layer such as is thought to occur in the Basin and Range province. Models of their geological and tectonic histories are most effectively constrained by data obtained from dense arrays such as LABPSE. This experiment will help determine whether crustal thinning from extension has occurred beneath the L.A. basin.

In the Backyard—Literally

One of the unique aspects of this experiment was the interaction with the homeowners whose backyards we used for seismometer locations. We are grateful to them for their enthusiastic permission to use their properties. One homeowner helped us build a stand to raise our GPS receiver, and his daughter helped us test our equipment by bouncing her ball as a vibration source.

The use of private homes had additional perks besides the obvious scientific advantages. One of our favorite sites was a home in La Puente where the owners had a lovely garden with wonderful herbs, trees, and flowers. The seismometer was in the corner of the yard and was guarded by a faithful duck whose house was next to the data recording system. We

Local help. In La Puente, homeowner Joe Baeli, assisted by daughter Elizabeth, is constructing a stand to raise our GPS receiver. Aaron Martin of the Institute of Crustal Studies is also pictured.

In a trailer park. The second station from the north end of the array. Elizabeth Cochran and Carmen Alex are pictured.

were treated to homegrown tomatoes in the garden of a Whittier homeowner. A Hacienda Heights homeowner offered us the use of his pool. However, we had to be careful of black widow spiders nesting in the cool, dark recesses of our equipment.

The most beautiful site was the northernmost station in the San Gabriel Mountains next to Morris Dam, but a forest fire prevented us from getting to that site for a week during the late summer. The most unusual sites were the southernmost three. One was next to an Armed Forces Reserve helicopter flight simulator building actively used in military training, and two were among nuclear missile storage bunkers purposely disguised with slanted grassy roofs so that they would not be easily observed by satellites.

The homeowners were eager to talk about their experiences with recent local earthquakes and wanted more information on current seismicity, geology, and relative shaking levels in their communities. It was satisfying to be able to show them actual seismograms recorded in their yards from felt earthquakes. Most were eager to find out how their house had fared relative to adjacent cities, given the geological environment and type of house they lived in. We were impressed with the depth and number of questions we were asked about regional faulting and seismicity. Los Angeles residents obviously know much more about earthquakes than they did 10 to 20 years ago. By installing our stations in backyards, we were able to take advantage of continuous power, equipment security, and easy access to the recording disks, which were swapped about once every three weeks.

The local events are being used by UCLA seismologists to quantify ground motion amplification in densely populated areas near the Whittier and Sierra Madre faults. Preliminary analysis shows an unexpected change in waveform character between the Puente Hills stations and adjacent stations to the north (San Gabriel Valley) and south (southern L.A. basin).

Results

Several earthquakes that occurred near the array have surprisingly impulsive P and S arrivals on San Gabriel Valley and L.A. basin records, but scattered or emergent arrivals for stations in the Puente Hills. A defocusing structure such as a sharply folded anticline would explain this observation. In addition, the horizontal waveforms for the basin stations are most amplified between Cerritos (south of Whittier) and Cypress (north of Seal Beach), the segment that corresponds to the region of maximum basin sedimentary thickness along the line.

The teleseismic data combined with Southern California Seismic Network data will be used in tomographic inversions for subcrustal lithospheric heterogeneity with greatly increased ray-path coverage and resolution beneath the deeper portions of the L.A. basin. Although the L.A. basin is a heavily studied region, there is a surprising dearth of teleseismic data. The waveforms from local networks are often difficult to read; if there is a question about the arrival time of a specific phase, none is reported. Moreover, no other networks are nearly as dense as LABPSE with three-component recording, precluding the study of small-scale structures in the lower crust/upper mantle. The three-dimensional images of seismic heterogeneity make it possible to evaluate the role of recent tectonics in the geologic history of the eastern L.A. basin.

The Preliminary Determination of Epicenters (PDE) Catalog produced by the USGS National Earthquake Information Center (NEIC) shows that 230 teleseismic events with magnitudes greater than 5.5 occurred during this experiment. According to catalog data supplied by the SCEC Data Center, 17 regional events and 2,280 locals events of M 2.0 occurred during the recording period. Notable local events included the March 18, 1997, Calico earthquake (M 5.3), as well as the April 26 and April 27, 1997, Northridge aftershocks (M 5.1 and 4.9).

Data processing will be completed this summer. The data will be archived at the Incorporated Research Institutions of Seismology (IRIS) Data Management Center and UCLA. Processing includes making time corrections using the GPS receiver timing data at each station and cutting the continuous data into 150-second (locals and teleseismic events) and 1-hour files (teleseismic events).

The waveforms will be used by SCEC researchers to test numerical predictions of ground motion amplitude variations caused by local earthquakes for a large range of azimuths. The clearly recorded teleseisms in the basin make an ideal test case to validate ground motion predictions using various 3D southern California upper-crustal velocity models. The operational success of arrays such as this and the LARSE passive array illustrate the potential value of a continuously migrating dense local array, making it possible to deploy seismometers for long periods in regions where instrumentation is sparse.

We thank Paul Davis, Aaron Martin, Bryan Kerr, Shirley Baher, Steve Persh, Andy Rigor, Geoff Ely, Kirsten Zellmer, Elizabeth Cochran, and Carmen Alex for assistance during this experiment. The equipment and maintenance of the experiment were made possible by the existence of the Portable Broadband Instrument Center at the Institute for Crustal Studies at UC Santa Barbara. Funding was provided by U.S.G.S. and SCEC.

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